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Fin Whale Acoustic Presence Increases by 3 d/y in the Migratory Corridor off Cape Leeuwin, Western Australia—An Indicator of Population Growth?

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Abstract

The population of southern fin whales (*Balaenoptera physalus quoyi*) was severely depleted by 19th and 20th century whaling. Its conservation status remains 'vulnerable', as recovery has been slow. Over 19 years of underwater acoustic recordings from the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO)'s hydrophones off Cape Leeuwin, Western Australia, were analyzed to monitor fin whales' annual migration from their Southern Ocean feeding grounds (where they spend the austral summer) to their tropical breeding grounds (where they spend the austral winter) and back. Northward migrants arrived ~2 d/y earlier (2002–2020). The number of hours with fin whale acoustic presence increased by ~49 h/y and the number of days with fin whale acoustic presence by ~3 d/y. Thus, by the end of the 19-year recording period, fin whales were acoustically present on 74 more days than at the beginning of recording. While changes in habitat function, climate, and ambient noise may affect migratory behavior, the most likely explanation is a post-whaling increase in the number of animals of this Southern Hemisphere subspecies.

Keywords: fin whale; *Balaenoptera physalus*; Cape Leeuwin; passive acoustic monitoring

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1. Introduction

Most baleen whale species are migratory, occupying high-latitude, polar waters during the summer months before dispersing to low-latitude, temperate/tropical waters during the winter months [1]. The purpose of this migration is to take advantage of the seasonally highly productive feeding grounds in polar waters and the warmer and more sheltered calving grounds in sub-equatorial waters, where energy requirements and risk of predation are lower [1,2]. The fin whale (*Balaenoptera physalus*) is no exception to this [3].

Passive acoustic monitoring (PAM) has enabled the extensive identification of the species' distribution and migration patterns around the world—based on its stereotypical vocalizations [4–8]. The most widely identified call type of the fin whale, referred to as the 20 Hz pulse, is ideal for PAM, as the pulses are strong (source levels up to 190 dB re 1 µPa m) and of low frequency (18–42 Hz) [9–14]—ideal for long-range propagation. The pulses are short (~1 s) and produced in highly stereotyped rhythmic sequences with inter-pulse intervals (IPs) of 7–26 s. These repetitive sequences (songs) are believed to only be produced by males as a breeding display, while single, irregular 20 Hz pulses may be produced by all demographic cohorts in association with social behaviors [15,16].

A recent PAM study has identified the long-term seasonal distribution and migratory pathways of the Southern Hemisphere subspecies of fin whale (*B. p. quoyi*) from their summer grounds in Eastern Antarctic waters to their winter grounds in temperate-to-tropical Australian waters [7]. Fin whales are seasonally present in Eastern Antarctica at the Southern Kerguelen Plateau from February to June (late summer and autumn) when they begin their migration to Australia [7]. Once they reach the southwestern tip of Australia at Cape Leeuwin, they continue to follow the Western Australian coastline through the Perth Canyon and into temperate-to-tropical waters [7,17].

Globally, studies have revealed long-term shifts in the presence and timing of migratory cetaceans: Earlier arrival times have been reported for humpback (*Megaptera novaeangliae*) and blue (*Balaenoptera musculus)* whales to low-latitude regions [18–20], and later departure times have been reported for bowhead (*Balaena mysticetus*) and beluga (*Delphinapterus leucas*) whales from high-latitude regions [21,22]. Such shifts in migration timing have also been reported for the fin whale in the North Atlantic, with the animals arriving earlier in the Gulf of St. Lawrence by ~1 d/y and departing earlier by ~0.4 d/y from 1984 to 2010 [23]. Whether other populations of fin whale shift their migration timing is unknown.

The fin whale is listed as vulnerable on the International Union for Conservation of Nature (IUCN) Red List [24] after severe population decline during the industrial whaling era, with ~700,000 animals caught in the Southern Hemisphere [25]. There have been few studies of fin whales in the Southern Hemisphere [26] and most have focused on Antarctic waters [27], particularly in the Atlantic and Pacific sectors [28–33]. Only a handful of contemporary studies of fin whales have been conducted in the temperate Southern Indian Ocean, with some being opportunistic or covering small geographic and temporal scales [34–37]. There are even fewer contemporary reports of fin whales in Australian waters [7,17].

In this study, we aimed to quantify the migratory acoustic presence of fin whales at Cape Leeuwin, which presents the first and last contact point with the Australian continent on their migration from and to Antarctica. We were specifically interested in any long-term trends. We analyzed 19 years of PAM data and present statistical measures of arrival and departure times. We discuss potential drivers of fin whale migration variability. Understanding shifts in fin whale migration may inform conservation management at a national (Australian) and international level.

2. Materials and Methods

Passive acoustic data were collected from the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) acoustic monitoring station (HA01) southwest of Cape Leeuwin, Western Australia (Figure 1). CTBTO has installed low-frequency hydrophones (sampling frequency: 250 Hz) in the SOFAR channel in every ocean to conduct long-range acoustic monitoring [38]. The hydrophones are cabled to shore and offer a continuous recording capability, making them suitable not just for their intended purpose of detecting nuclear explosions, but also for civil and scientific purposes such as the environmental monitoring of ice and ocean temperature [39] and the detection of whales [40,41]. Continuous recordings from Cape Leeuwin were obtained for the period of 1 January 2002–31 December 2020. For data analysis, recordings were split into 1 h samples.

In order to detect fin whale 20 Hz pulses in these recordings, a combined automatic and manual detection and verification process was implemented (see details in [7,17]). Briefly, the automatic detector was a spectrogram cross-correlator using a 20 Hz pulse template from Western Australia. Its performance had previously been assessed at a different site (0.27% false positive files and 1.62% false negative files for fin whale 20 Hz

presence/absence per file [7]). All files with automated detections were manually validated by checking that the detections were pulses downsweeping from ~40 Hz to 18 Hz with a 1 s duration and that they occurred in repetitive patterns. False positives were manually removed and false negatives added as appropriate. Finally, a process of 'bracketing' was carried out, whereby all audio files without automatic detections within ±3 h of a file with a verified detection were manually inspected for missed pulses, and pulses were added as appropriate. This process was iterated until all files surrounding a file with validated pulses were found to not contain fin whale pulses. The date and time of each fin whale pulse were noted.

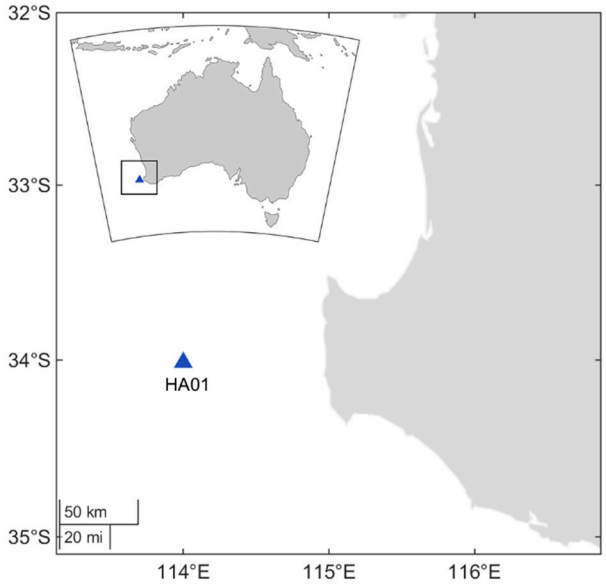


Figure 1. Location of the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) HA01 hydroacoustic monitoring station off Cape Leeuwin, Western Australia.

From the time series of verified fin whale 20 Hz pulse detections, we computed hourly presence/absence, the cumulative number of acoustic presence hours (i.e., pulse-hours) per day and per year, and the total number of days with fin whale pulses (i.e., pulse-days). To test for trends in fin whale acoustic presence at Cape Leeuwin, the first and last detection dates (of the fin whale season) and the total pulse-hours and pulse-days were each regressed on year. Simple linear regressions were performed using R statistical software version 4.2.2 [42].

3. Results

The fin whale 20 Hz pulse was detected across all acoustic recording years at Cape Leeuwin from 2002 to 2020 (Figure 2), with a total of 1233 days and 9938 h of acoustic presence. The detector performance included 0.81% false positive files and 4.51% false negative files before manual validation.

Across the 19 years of acoustic recordings at Cape Leeuwin, fin whale 20 Hz pulses were regularly detected from April to October (i.e., from austral autumn to mid-spring). Peaks in hourly acoustic presence were generally consistent across years, occurring in July and August (Figure 3). Acoustic detections did not split into two separate northern and southern migrations.

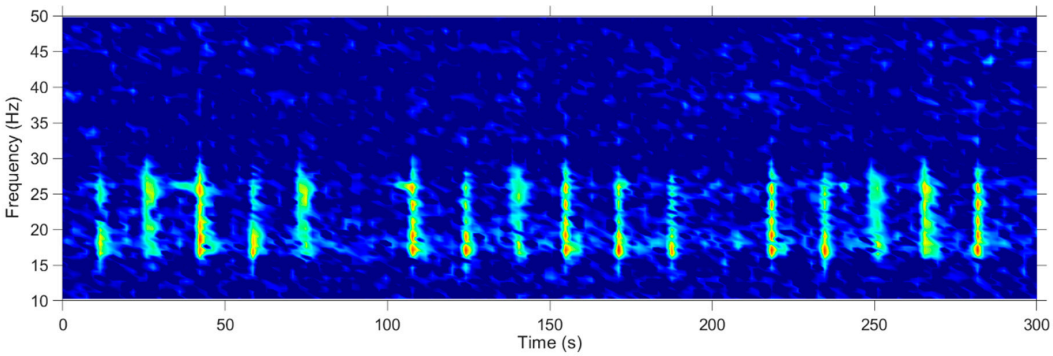


Figure 2. Spectrogram example of a fin whale 20 Hz pulse sequence. Recording from Cape Leeuwin (18 July 2012, 05:00). Spectrograms were calculated in 256-point Hann windows, 1 Hz and 1 s resolution, 50% overlap; sampling frequency: 250 Hz. Colors represent acoustic power (low: blue; high: red).

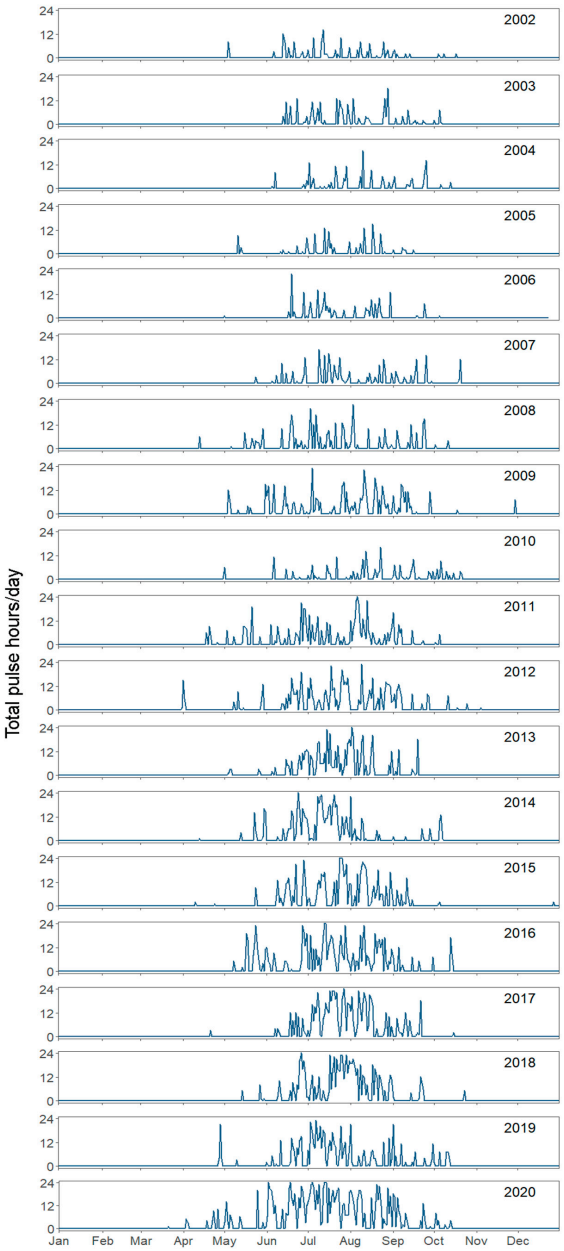


Figure 3. Line graphs of the total number of hours per day with fin whale 20 Hz acoustic presence (pulse-hours per day) across all years.

The first detection of fin whale acoustic presence shifted significantly over the study period, with earlier first detection by 2.14 d/y (Figure 4A). However, from 2013 to 2019, this trend waned, with a greater variation in the first detection date during this period (Figure 4A). The exception to this was in 2020, which observed the earliest first detection date of fin whale acoustic presence across all years (20th of March) (Figures 3 and 4A). The latest first detection date occurred on the 13th of June 2003 (Figures 3 and 4A). The last detection date of fin whale acoustic presence did not significantly shift across the study period (Figure 4B); acoustic presence commonly ceased in mid-October. An anomaly of last detection occurred in the year 2015, with fin whale acoustic presence detected much later in the year on the 27th of December (Figures 3 and 4B).

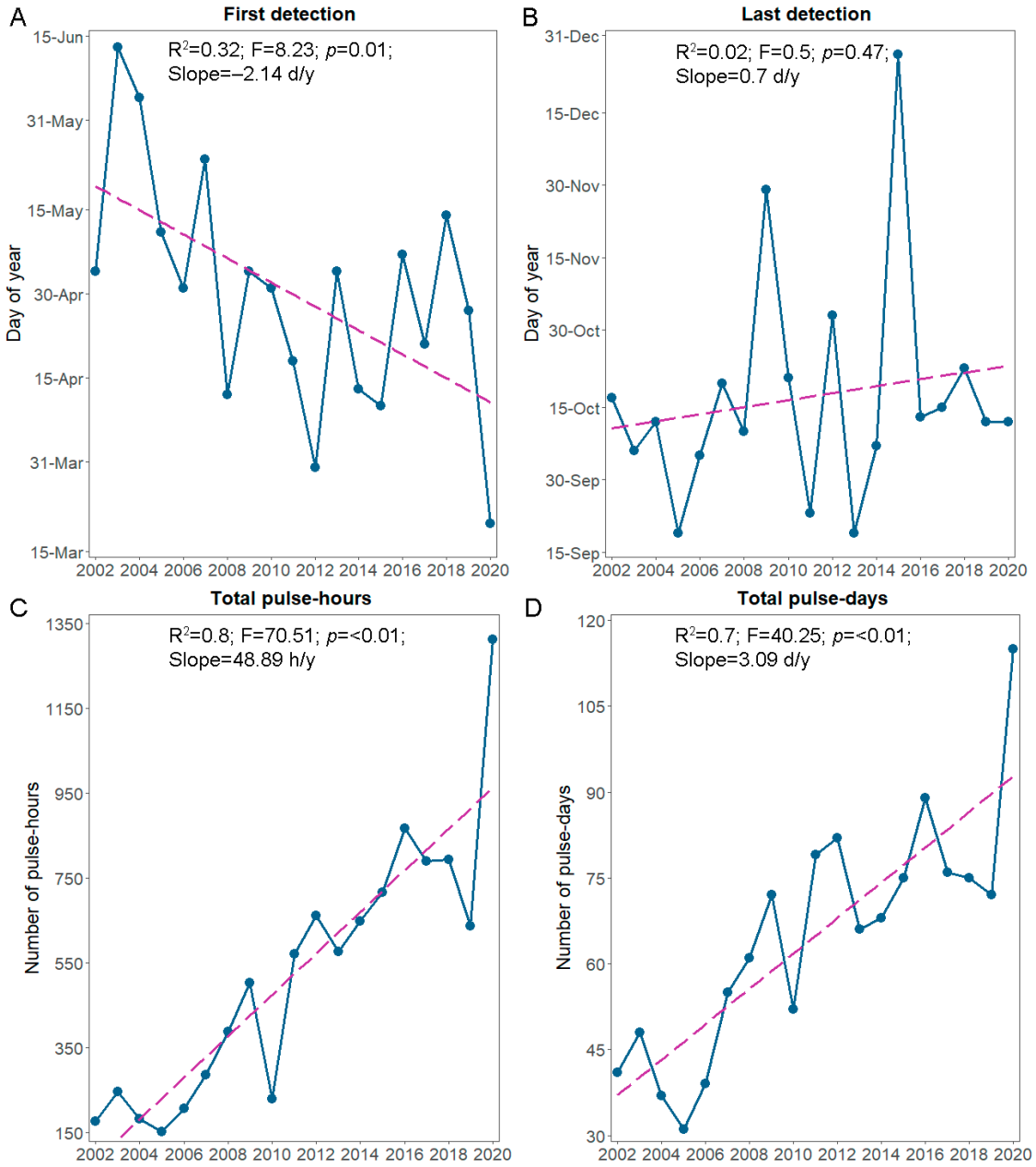


Figure 4. Scatterplots of fin whale (**A**) first detection, (**B**) last detection, (**C**) total pulse-hours per year, and (**D**) total pulse-days per year at Cape Leeuwin between 2002 and 2020. Regression statistics (R^2, F, *p*-value, and slope) are noted within each plot.

The total number of pulse-hours and pulse-days significantly increased from 2002 to 2020, with 48.89 more pulse-hours/y and 3.09 more pulse-days/y (Figure 4C,D). Both pulse-

hours and pulse-days were low in 2002 with a total of 176 h and 41 d, respectively, before declining to a minimum of 153 pulse-hours and 31 pulse-days in 2005. Fin whale acoustic presence substantially increased in 2020, with a maximum of 1312 and 115 pulse-hours and pulse-days, respectively (Figure 4C,D).

4. Discussion

In this study, we identified 19 years (2002–2020) of fin whale seasonal acoustic presence at Cape Leeuwin, Western Australia, from austral autumn to mid-spring. No observations of year-round fin whale 20 Hz calls were made across the 19 years, providing no evidence of resident, non-migratory animals, in contrast to reports of resident populations in the Northern Hemisphere [6,43]. This long-term pattern reinforces Cape Leeuwin as a key location along the fin whale migratory pathway from Eastern Antarctic to Australian waters. Interestingly, PAM did not identify two separate migrations (northern vs. southern) at Cape Leeuwin. Some animals might have already traveled south, while others were still traveling north. Such an acoustic blurring of northern and southern migrations was observed for humpback whales in the Perth Canyon over a 16 y period, where a brief notch in the presence-hours per day was only seen in some years [18]. Alternatively, most adult males might cease their singing during the southern migration away from the breeding grounds to the feeding grounds. This hypothesis is supported by the rare acoustic detections in November and December (2009, 2015; Figure 3). Acoustically reduced, if not absent, southern migrations have also been reported for pygmy blue whales in the Perth Canyon [44]. Finally, singing males might travel farther from shore on a more direct great-circle route to their southern feeding grounds, with only mothers and calves hugging the coast for shelter. PAM further offshore or biotelemetry research might shed light on this.

At Cape Leeuwin, fin whale acoustic presence increased such that by the end of the 19-year recording period, fin whales were acoustically present on 74 more days than at the beginning (from 41 to 115 pulse-days). This increase in pulse-hours and pulse-days across the two decades may have been indicative of an increased number of individual fin whales in this region of the Southern Hemisphere. A recent study at the Western Antarctic Peninsula identified the occurrence of high numbers of fin whales (7909) at their historic feeding grounds at Elephant Island in 2018 [45] in comparison to density estimations in the Antarctic Peninsula in 2000 (4672 whales)—likely a sign of a recovering population after intense whaling. The fin whale population abundance, circumpolar south of 60°, was estimated to be 5445 whales between 1991 and 1998 [27]. However, no further abundance estimates are available for fin whales in Eastern Antarctic and Australian waters. Other species in Antarctic waters that suffered a similar population decline during the commercial whaling era are also reported to have increased in their abundance and population size. The western South Atlantic (WSA) humpback whale population recovered to 93% of their pre-industrial whaling era size [46]. The Antarctic blue whale population occupying South Georgia waters has increased in sightings and "D" calls [47]. If the increase in pulse-days is due to an increase in fin whale numbers, this may be the first preliminary indication of a recovering population of fin whales in Eastern Antarctic and Australian waters. Future research may consider the expansion of PAM over additional years and sites, visual surveys, photo-ID and mark-recapture, and genetic sampling to confirm fin whale population trends [48–51].

Alternatively, the trend of increasing acoustic presence per year at Cape Leeuwin may reflect an alteration in the animals' acoustic behavior. Fin whale vocalization rates are suggested to vary with acoustic behaviors such as reproductive displays, social displays, or feeding activities [9,16,52]. The reproductive acoustic displays of the fin whale can last up to 32 h [9], while social displays are irregular and inconsistent [16]. The observed increase in

pulse detection rates at Svalbard Islands was likely due to this acoustic behavioral change, with the animals switching from irregular 20 Hz pulses to reproductive 20 Hz songs [53]. A similar shift in 20 Hz production rates at Cape Leeuwin may result in the animals vocalizing for longer time periods, resulting in greater acoustic presence hours and days per year.

Moreover, changes in the detection range of the acoustic system may affect pulse counts at Cape Leeuwin. The acoustic detection range could change with ambient noise, metocean and thus sound propagation conditions, fin whale swim depth and distance from shore, and call peak frequency. Some studies have shown a gradual decrease in low-frequency ambient noise at Cape Leeuwin, even after the removal of blue and fin whale calls [39,54,55]. The ambient noise in an area includes biotic (e.g., whale choruses), abiotic (e.g., wind), and anthropogenic noise (e.g., vessel traffic) and can affect the signal-to-noise ratio of a 20 Hz pulse, thereby affecting the detectability of the pulse [44]. The increasing temperature and acidification of the ocean might improve sound transmission but would affect signals and noises similarly [56]. If whales gradually migrated closer to shore or at new depths from which calls might better propagate to the Cape Leeuwin hydroacoustic station, then detectability would increase [40,57]. Finally, long-term shifts in call peak frequency [58] may lead to gradual, albeit small, changes in detection ranges.

The shift in fin whale first acoustic presence at Cape Leeuwin by ~2 d/y may be due to the animals varying their migration timing out of Antarctic waters. Recent studies have identified environmental variables which affect fin whale acoustic presence in regions around the world, such as sea surface temperature and chlorophyll-a concentration [59,60]. A long-term seasonal shift in fin whale first and last sightings at their feeding grounds in the Gulf of St. Lawrence, Canada was attributed to declining sea ice coverage and rising sea surface temperature in this region due to climate change [23]. Moreover, climate change is expected to impact Antarctic krill, reducing prey availability on fin whale feeding grounds [61,62], which might trigger earlier fin whale departure. The investigation of environmental variables that may drive fin whale migration out of Antarctic waters could shed light on the shift in the first acoustic presence of the fin whale along their migratory route at Cape Leeuwin.

The substantial increase in fin whale acoustic presence at Cape Leeuwin in 2020 may reflect an indirect effect of the COVID-19 pandemic. During the height of the pandemic in 2020, lockdown restrictions resulted in a reduction in anthropogenic activity such as commercial fishing, shipping, recreational boating, and tourism activities in Western Australia [63]. Throughout the lockdown period in 2020, there was a global increase in sightings of marine mammal species, which were likely related to changes in the behavior and distribution of the animals [64]. These changes were thought to be the result of a reduction in the physical disturbance and displacement of the animals or a reduction in underwater noise due to the decrease in vessel traffic [64]. As fin whales have been reported to be affected by vessel traffic and the resulting ambient noise [65,66], it is possible that the increase in the acoustic presence of the animals at Cape Leeuwin in 2020 was due to these environmental effects of the COVID-19 lockdowns. Similarly linked to the COVID-19 pandemic, the detection range of the acoustic systems at Cape Leeuwin may have been positively affected by a decrease in ambient noise due to reduced vessel traffic. Further analysis of the ambient noise environment and shipping activity combined with additional, consecutive acoustic recording years at this site may help to identify why there was a greater acoustic presence in 2020 in comparison to not only the prior but also the later years.

It is important to note that the first and last detections of fin whale vocalizations may not be a reliable representation of when fin whales arrive and depart Australian waters on their north- and southward migrations, respectively. The observations reported here only represent vocalizing fin whales and do not confirm the absence of the whales, as

there may be animals that are present but silent. Visual survey, biotelemetry, and tagging with acoustic recorders may allow the determination of vocalization rates and quantify the uncertainty of physical presence derived from PAM only.

5. Conclusions

Our investigation of 19 years of fin whale acoustic presence at Cape Leeuwin, Western Australia, from 2002 to 2020 revealed a seasonal pattern of presence from austral autumn to mid-spring. The long-term consistency of presence at this southwesternmost point of the Australian continent reinforces this site as a key migratory point for the species as it heads for Australia from Antarctica, and vice versa, warranting further research to ultimately inform conservation policies in migratory corridors. Moreover, the observed increase in fin whale 20 Hz pulse-hours and pulse-days across the 19 years provides evidence of an increasing population of this vulnerable subspecies in the Southern Hemisphere, which remains to be confirmed with complementary survey methods to fully assess recovery under the IUCN.

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Abbreviations

The following abbreviation is used in this manuscript:

PAM Passive acoustic monitoring

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